ÖGH Herpetozoa
Austrian Herpetological Society

Herpetozoa 32: 165–169 (2019)
DOI 10.3897/herpetozoa.32.e36609

Eaten or beaten? Severe population decline of the invasive lizard *Podarcis siculus* (Rafinesque-Schmaltz, 1810) after an eradication project in Athens, Greece

Chloe Adamopoulou[1,2], Panayiotis Pafilis[1,2,3]

1 *Section of Zoology - Marine Biology, Department of Biology, National & Kapodistrian University of Athens, Panepistimiopolis 15701 Athens, Greece*
2 *Hellenic Herpetological Society, Knossos Ave, 71409, Heraklion, Crete, Greece*
3 *Zoological Museum, National and Kapodistrian University of Athens, Greece*

http://zoobank.org/225CD5A7-C203-4480-9D51-61D81EA42C82

Corresponding author: *Chloe Adamopoulou* (cadam@biol.uoa.gr)

Academic editor: *Yurii Kornilev* ♦ **Received** 29 May 2019 ♦ **Accepted** 19 July 2019 ♦ **Published** 30 July 2019

Abstract

Invasive species have been recognised as an important hazard to native communities. Amongst the mitigation measures that have been proposed to confront biological invasions, eradication projects are certainly the most drastic. In this short communication, a successful eradication project against a recently established population of the Italian wall lizard (*Podarcis siculus*) in Athens, Greece, is reported. To this aim, the Hellenic Herpetological Society received unforeseen aid from stray cats and, possibly, from the Ocellated skink (*Chalcides ocellatus*) and vegetation growth. Within three years, the initial thriving *P. siculus* population has shrunk to very few individuals.

Key Words

cat predation, invasive, Italian wall lizard, urban biodiversity

Invasive species are acknowledged as one of the most serious threats to global biodiversity (Millennium Ecosystem Assessment 2005). Often being highly adaptive and ecologically aggressive, they may have a strong impact on native biocommunities and may drive local populations down to the brink of extinction. Reptilian invasive species follow the same pattern. Though the list of 100 of the World's Worst Invasive Alien Species includes only two reptiles (ISSG 2015), many more species are known to cause serious problems to native species and communities. The Italian wall lizard, *Podarcis siculus* (Rafinesque-Schmaltz, 1810), is an outstanding example of a successful settler and a serious hazard to other lizard species (Kraus 2009).

Podarcis siculus is a small-bodied (snout-vent length up to 90 mm), diurnal, heliothermic lacertid (Corti 2006). Its native distribution spreads through the Italian peninsula, Sicily and the north Adriatic coast. However, this species is notorious for its high colonising potential; besides Europe, so far, *P. siculus* has established several thriving populations on three continents – Africa, Asia and North America (Corti et al. 2011; Kolbe et al. 2013; Donihue et al. 2014). In Europe, the species expanded its distribution to southern France, Spain, Portugal, European Turkey and many Mediterranean islands (Crnobrnja-Isailovic et al. 2009).

The opportunistic profile of the species seems to support its colonising success. *Podarcis siculus* has a generalist diet (Sicilia et al. 2001; Capula and Aloise 2011; Mačát et al. 2015) and an impressive digestive (Herrel et al. 2008; Vervust et al. 2010) and thermoregulatory (Kapsalas et al. 2016) plasticity. Thanks to these skills, it could greatly affect native lizard populations within its new range through competition for environmental resources (Vanhooydonck et al. 2000; Capula et al. 2002). Additionally, *P. siculus*

Copyright *Chloe Adamopoulou, Panayiotis Pafilis*. This is an open access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

may menace other lizards in more direct ways, such as hybridisation (Capula 1993, 2002), behavioural interference (Downes and Bauwens 2002) or even predation (Cattaneo 2005; Capula and Aloise 2011). It has excellent dispersal abilities (Vignoli et al. 2012) and, taking advantage of anthropogenic activities, constantly broadens its distribution (Deichsel et al. 2010; Silva-Rocha et al. 2012).

In 2014, a new introduced population was discovered in Athens, Greece (Adamopoulou 2015), probably coming from the Adriatic region (Silva-Rocha et al. 2014). As such, the newly found Athenian population represented a peril for Greek endemic lizards e.g. on Aegean islands (Lymberakis et al. 2018). The alien lizard colony was discovered in March 2014 inside an artificial park in Palaio Faliro, within a narrow, sandy zone (90 × 15 m) between a crowded beach and a tram-line (37°55'9.38"N, 23°42'0.50"E). In 2011, this area was planted with mostly exotic vegetation. Trees and shrubs such as oleanders (*Nerium oleander*), yuccas (*Yucca aloifolia*) and desert fan palms (*Washingtonia filifera*) grew quickly and soon covered the focal area. Three years later, upon its discovery, the lizard population size was estimated at approximately 60 adults and numerous subadults (Adamopoulou 2015). During later visits in 2015, it seemed to have undergone rapid growth, presumably due to high food availability (e.g. plant fruits, insects and even organic wastes).

Several approaches have been proposed for the management of "newcomer" urban biodiversity, including eradication (Gaertner et al. 2016). Eradication projects have been applied in numerous cases and places (Genovesi 2005) and, despite the often high costs in carrying them out successfully (human effort, time, financial cost), they have been proven useful (e.g. Guo 2006; Howald et al. 2007). In 2015, the Hellenic Herpetological Society (HHS) launched an eradication project in order to prevent further expansion of *P. siculus*. Here, we report the successful outcome of this project. The HHS adopted the eradication procedure undertaken on the invasive *P. siculus* in the United Kingdom (Hodgkins et al. 2012) that consisted of quick action and removal of invasive individuals. In this case, thanks to the rapid action undertaken by the British National Trust, the establishment of a *P. siculus* population was prevented.

From April 2015 through July 2018, members of HHS and students of the National and Kapodistrian University of Athens (NKUA) visited the site regularly under appropriate weather conditions. Visits were scheduled during the morning hours of the lizards' peak activity. Researchers walked slowly back and forth throughout the area, visually inspecting all available microhabitats. Lizards were caught by noosing. Captured individuals were transported to NKUA facilities, used in ecological, physiological and behavioural studies before being euthanised, according to the guidelines of AVMA (2013) and deposited to the Herpetological Collection of the NKUA Zoological Museum.

A total of 204 lizards (66 males, 85 females and 53 juveniles) (Table 1) were collected. During the last 2 surveys (summer 2018), fewer than 10 lizards were seen per visit. Almost all of them were found outside the area in which the population was situated at the beginning. They were located in two small well-defined areas at the periphery of the park. The first spot was a sandy area (53 × 3.5 m) occupied entirely by sour fig, *Carpobrotus* sp., an invasive plant widely spread in the Mediterranean coast and forming dense mats. The second one is impenetrable wire netting rubble (4 × 2 m). No individual was found inside the park where the colony was first detected. Though not complete, the removal of large numbers of the introduced lizard seemed to halt the initial demographic increase. However, in this effort, there were some unexpected allies: cats, skinks and vegetation.

Table 1. Sex and age of *Podarcis siculus* caught during the removal events in Palaio Faliro, Athens, Greece.

Month of removal events	Number of lizards removed			
	Male	Female	Sub./Juv.	Total
April 2015	9	24	4	37
May 2015	13	18	6	37
October 2015	13	15	12	40
December 2015	2	1	2	5
November 2016	1	1	5	7
February 2016	1	2	4	7
March 2016	5	7	2	14
June 2016	2	6	4	12
March 2017	4	1	–	5
May 2017	2	4	5	11
July 2017	2	3	5	10
October 2017	4	2	4	10
June 2018	5	–	–	5
July 2018	3	1	–	4
Total	66	85	53	204

Cats are amongst the most efficient saurophagous predators (Grayson and Calver 2004; Van Heezik 2010). In the Mediterranean, cats frequently prey on lizards and, especially on islands, represent one of the main threats for native lizards (Medina and Nogales 2009; Li et al. 2014). Cats have been reported preying on European populations of *P. siculus* (Salvador 2015) and (together with other factors) have facilitated the decrease and eradication of introduced populations in the US (Burke and Deichsel 2008). Numerous stray cats (around 20) in the park were frequently seen catching lizards (Fig. 1). We strongly believe that this "paw of help" was an important factor in the decrease of the *P. siculus* population.

Another possible accessory to the eradication was the Ocellated skink, *Chalcides ocellatus* (Forsskål, 1775), which also occurs in the area in great densities. *Chalcides ocellatus* has been reported to prey on Filfola lizard, *Podarcis filfolensis* (Bedriaga, 1876), juveniles on Lampione Island, Italy (Carretero et al. 2010). *Podarcis siculus* juveniles are chased and eaten by other skink species in the introduced US populations (Burke and Deichsel 2008). Thus, it would be reasonable to expect that the much larger *C. ocellatus* would also prey on *P. siculus*.

Figure 1. *Podarcis siculus* adult just caught by a stray cat in Palaio Faliro, Athens, Greece.

Figure 2. Study area (**A**) in 2015, when the *Podarcis siculus* population was found and (**B**) in 2018. Notice the difference in vegetation cover.

Besides dynamic predation, the constant growth of the mostly exotic vegetation has created a canopy that greatly reduces the sunlight reaching the ground, thus decreasing the thermal suitability of the habitat. *Podarcis siculus* is a precise and accurate thermoregulator that maintains relatively high body temperatures (Van Damme et al. 1990; Tosini et al. 1992). It prefers open areas (Salvador 2015; Sindaco et al. 2016); in highly vegetated habitats, its populations have been reported to maintain low densities, mainly due to the low environmental temperatures (Ouboter 1981). The effectiveness of thermoregulation of the Athenian population was the highest ever achieved by a *Podarcis* lizard (Kapsalas et al. 2016). During 2014, the source site was nearly an open area with scattered seedlings and palm trees; lizards were either on bare sand or climbing on palm trees. In 2018, the vegetation in the park was lush and did not provide lizards with sufficient basking sites (Figs 2A, B). The few remaining individuals, not accidentally, were found only in the two marginal spots, where sour fig mats and wire netting rubble offer places for thermoregulation and protection from cats.

In summary, the Athenian colony corroborated the general pattern of other *P. siculus* introduced populations that thrive in disturbed or highly altered habitats (Burke and Deichsel 2008). Since eradication of alien reptile populations is virtually impossible once they are established (Kraus 2009), human efforts should be rapid and focused on eradicating the invasive species as soon as they are detected to prevent further expansion. Regarding the Athenian population, it seems that the combination of biotic factors (heavy predation pressure by stray cats and possibly by the skink, as well as by deterioration of habitat thermal quality), together with the eradication project run by HHS, account for its dramatic decline. This case may represent a paradigm of how human actions, in synergy with natural causes, may show positive results in controlling an invasive reptile population within urban environments.

Acknowledgements

We thank two anonymous reviewers for their constructive comments. Permits for lizard eradication were issued by the Greek Ministry of Environment & Energy (2015: 61ΣΜ465ΦΘΗ-ΕΣ6; 2016: ΩΨ564653Π8-2Ι2; 2017: Ψ6ΕΟ4653Π8-ΩΝΛ). We thank Konstantina Mitsi, Grigoris Kapsalas, Aris Tsikoutas-Deimezis, Tasos Limnios, Ismini Gourtsouli-Antoniadou, Pelagia Mitsi, Natalia Gourgouliani, Ioanna Gavriilidou, Alexandros Vezyrakis, Ana Pereira and Stratos Kafentzis for helping us catch lizards in the field.

References

Adamopoulou C (2015) First record for *Podarcis siculus* (Rafinesque-Schmaltz, 1810) from Greece. Herpetozoa 27: 187–188.

AVMA (2013) Guidelines for the Euthanasia of Animals. Version 2013.0.1. American Veterinary Medical Association, Schaumburg, IL, USA.

Burke R, Deichel G (2008) Lacertid lizards introduced into North America: History and Future. In: Mitcell JC, Brown JRE, Bartholomew B (Eds) Urban Herpetology. Society for the Study of Amphibians and Reptiles, USA, 347–355.

Capula M (1993) Natural hybridization in *Podarcis sicula* and *P. wagleriana* (Reptilia: Lacertidae). Biochemical Systematics and Ecology 21: 373–380. https://doi.org/10.1016/0305-1978(93)90028-P

Capula M (2002) Genetic evidence of natural hybridization between *Podarcis sicula* and *Podarcis tiliguerta* (Reptilia). Amphibia–Reptilia 23: 313–321. https://doi.org/10.1163/15685380260449199

Capula M, Aloise G (2011) Extreme feeding behaviors in the Italian wall lizard, *Podarcis siculus*. Acta Herpetologica 6: 11–14. http://dx.doi.org/10.13128/Acta_Herpetol-9573

Capula M, Luiselli L, Bologna MA, Ceccarelli A (2002) The decline of the Aeolian wall lizard, *Podarcis raffonei*: causes and conservation proposals. Oryx 36: 66–72. https://doi.org/10.1017/S0030605302000108

Carretero MA, Lo Cascio P, Corti C, Pasta S (2010) Sharing resources in a tiny Mediterranean island? Comparative diets of *Chalcides ocellatus* and *Podarcis filfolensis* in Lampione. Bonn zoological Bulletin 57: 111–118.

Cattaneo A (2005) L'Erpetofauna della Tenuta Presidenziale di Castelporziano (Roma). Atti del Museo di Storia Naturale della Maremma 21: 49–77.

Corti C (2006) *Podarcis sicula*. Lucertola Campestre, Italian Wall Lizard. In: Sindaco R, Doria G, Razzetti E, Bernini F (Eds) Atlante degli Anfibi e dei Rettili d'Italia. Atlas of Italian Amphibians and Reptiles. Polistampa, Firenze, 486–489.

Corti C, Biaggini M, Capula M (2011) *Podarcis siculus* (Rafinesque–Schmaltz, 1810). In: Corti C, Capula M, Luiselli L, Razzetti E, Sindaco R (Eds) Fauna d' Italia: Reptilia, Vol. XLV. Edizioni Calderini de Il Sole 24 ORE. Editoria Specializzata S.r.l., Bologna, 407–417.

Crnobrnja–Isailovic J, Vogrin M, Corti C, Pérez Mellado V, Sá–Sousa P, Cheylan M, Pleguezuelos J, Sindaco R, Romano A, Avci A (2009) *Podarcis siculus* (errata version published in 2016). The IUCN Red List of Threatened Species 2009.

Deichsel G, Nafis G, Hakim J (2010) *Podarcis siculus* (Italian Wall Lizard) USA: California. Herpetological Review 41: 513–514.

Donihue CM, Lambert MR, Watkins-Colwell GJ (2014) *Podarcis sicula*: The first population found in New England. Herpetological Review 45(4): 661–662.

Downes S, Bauwens D (2002) An experimental demonstration of direct behavioral interference in two Mediterranean lacertid lizard species. Animal Behaviour 63: 1037–1046. https://doi.org/10.1006/anbe.2002.3022

Gaertner M, Larson BMH, Irlich UM, Holmes PM, Stafford L, van Wilgen BW, Richardson DM (2016) Managing invasive species in cities: A framework from Cape Town, South Africa. Landscape and Urban Planning 151: 1–9. https://doi.org/10.1016/j.landurbplan.2016.03.010

Genovesi P (2005) Eradications of invasive alien species in Europe: a review. Biological Invasions 7: 127–133. https://doi.org/10.1007/s10530-004-9642-9

Grayson J, Calver M (2004) Regulation of domestic cat ownership to protect urban wildlife: a justification based on the precautionary principle. In: Lunney D, Burgin S (Eds) Urban Wildlife: More than meets the eye. Royal Zoological Society of New South Wales, Mosman NSW, Australia, 169–178. https://doi.org/10.7882/FS.2004.094

Guo J (2006) The Galapagos islands kiss their goat problem goodbye. Science 313: 1567. https://doi.org/10.1126/science.313.5793.1567

Herrel A, Huyghe K, Vanhooydonck B, Backeljau T, Breugelmans K, Grbac I, Van Damme R, Irschick DJ (2008) Rapid large scale evolutionary divergence in morphology and performance associated with exploitation of a different dietary resource. Proceedings of the National Academy of Sciences 105: 4792–4795. https://doi.org/10.1073/pnas.0711998105

Hodgkins J, Davis C, Foster J (2012) Successful rapid response to an accidental introduction of non-native lizards *Podarcis siculus* in Buckinghamshire, UK. Conservation Evidence 9: 63–66.

Howald G, Donlan C, Galvan J, Russell J, Parkes J, Samaniego A, Wand Y, Veitch D, Genovesi P, Pascal M, Saunders A, Tershy B (2007) Invasive rodent eradication on islands. Conservation Biology 21: 1258–1268. https://doi.org/10.1111/j.1523-1739.2007.00755.x

ISSG [Invasive Species Specialist Group] (2015) The Global Invasive Species Database. Version 2015.1. http://www.iucngisd.org/gisd [Accessed 2 October 2018]

Kapsalas G, Gavriilidi I, Adamopoulou C, Foufopoulos J, Pafilis P (2016) Effective thermoregulation in a newly established population of *Podarcis siculus* in Greece: a possible advantage for a successful invader. Acta Herpetologica 11: 111–118.

Kolbe JJ, Lavin BR, Burke RL, Rugiero L, Capula M, Luiselli L (2013) The desire for variety: Italian Wall lizard (*Podarcis siculus*) populations introduced to the United States via the pet trade are derived from multiple native-range sources. Biological Invasions 15: 75–783. https://doi.org/10.1007/s10530-012-0325-7

Kraus F (2009) Alien Reptiles and Amphibians: A Scientific Compendium and Analysis. Springer, New York, 563 pp. https://doi.org/10.1007/978-1-4020-8946-6

Li B, Belasen A, Pafilis P, Bednekoff P, Foufopoulos J (2014) Effects of feral cats on the evolution of antipredator behaviors in island reptiles: insights from an ancient introduction. Proceedings of the Royal Society B 281: 2014033. https://doi.org/10.1098/rspb.2014.0339

Lymberakis P, Pafilis P, Poulakakis N, Sotiropoulos K, Valakos ED (2018) The Amphibians and Reptiles of the Aegean Sea. In: Sfenthourakis S, Pafilis P, Parmakelis A, Poulakakis N, Triantis KA (Eds) Biogeography and Biodiversity of the Aegean. In honour of Prof. Moysis Mylonas. Broken Hill Publishers Ltd, Nicosia, Cyprus, 169–189.

Mačát Z, Veselý M, Jablonski D (2015) New case of fruit eating observation in *Podarcis siculus* (Rafinesque-Schmaltz, 1810) (Lacertidae) from Croatia. Biharean Biologist 9: 158–159.

Medina FM, Nogales M (2009) A review on the impacts of feral cats (*Felis silvestris catus*) in the Canary Islands: implications for the conservation of its endangered fauna. Biodiversity and Conservation 18: 829–846. https://doi.org/10.1007/s10531-008-9503-4

Millennium Ecosystem Assessment (2005) Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC, 86 pp.

Ouboter PE (1981) The ecology of the island lizard *Podarcis sicula salfi*: correlations of microdistribution with vegetation coverage, thermal environment and food size. Amphibia–Reptilia 2: 243–257. https://doi.org/10.1163/156853881X00078

Salvador A (2015) Lagartija italiana – *Podarcis siculus*. In: Salvador A, Marco A (Eds) Enciclopedia Virtual de los Vertebrados Españoles. Museo Nacional de Ciencias Naturales, Madrid. http://www.vertebradosibericos.org/

Sicilia A, Violani C, Zava B (2001) Predazione di *Podarcis sicula* su *Discoglossus pictus*. Atti 3° Congresso Nazionale della Societas Herpetologica Italica (Pavia, 14-16/9/2000), Pianura 13: 283–284.

Silva-Rocha I, Salvi D, Carretero MA (2012) Genetic data reveal a multiple origin for the populations of the Italian Wall lizard *Podarcis sicula* (Squamata: Lacertidae) introduced in the Iberian Penin-

sula and Balearic Islands. Italian Journal of Zoology 79: 502–510. https://doi.org/10.1080/11250003.2012.680983

Silva-Rocha I, Salvi D, Harris DJ, Freitas S, Davis C, Foster J, Deichsel G, Adamopoulou C, Carretero MA (2014) Molecular assessment of *Podarcis sicula* populations in Britain, Greece and Turkey reinforces a multiple-origin invasion pattern in this species. Acta Herpetologica 9: 253–258. https://doi.org/10.13128/Acta_Herpetol-14968

Sindaco R, Restivo S, Zuffi MAL (2016) *Podarcis siculus* (Rafinesque, 1810) (Lucertola campestre). In: Stoch F, Genovesi P (Eds) Manuali per il monitoraggio di specie e habitat di interesse comunitario (Direttiva 92/43/CEE) in Italia: Specie animali. Anfibi e Rettili. ISPRA: 282–315.

Spilani L, Strachinis I, Lampropoulos A, Tsigas P, Poulakakis N, Pafilis P (2018) *Podarcis vaucheri* (Sauria: Lacertidae) far away from home: a new invasive species in Greece. Amphibia–Reptilia 39: 363–368. https://doi.org/10.1163/15685381-18000002

Tosini G, Foà A, Avery RA (1992) Body temperatures and exposure to sunshine of ruin lizards *Podarcis sicula* in central Italy. Amphibia-Reptilia 13: 169–175. https://doi.org/10.1163/156853892X00355

Van Damme R, Bauwens D, Castilla AM, Verheyen RF (1990) Comparative thermal ecology of the sympatric lizards *Podarcis tiliguerta* and *Podarcis sicula*. Acta Oecologica 11: 503–512.

Van Heezik Y (2010) Pussyfooting around the issue of cat predation in urban areas. Fauna & Flora International. Oryx 44:153–154. https://doi.org/10.1017/S003060531000027X

Vanhooydonck B, Van Damme R, Aerts P (2000) Ecomorphological correlates of habitat partitioning in Corsican lacertid lizards. Functional Ecology 14: 358–368. https://doi.org/10.1046/j.1365-2435.2000.00430.x

Vervust B, Pafilis P, Valakos ED, Van Damme R (2010) Anatomical and physiological changes associated with a recent dietary shift in the lizard *Podarcis sicula*. Physiological and Biochemical Zoology 83: 632–642. https://doi.org/10.1086/651704

Vignoli L, Vuerich V, Bologna MA (2012) Experimental study of dispersal behavior in a wall lizard species (*Podarcis sicula*) (Sauria: Lacertidae). Ethology Ecology and Evolution 24: 244–256. https://doi.org/10.1080/03949370.2011.643922